A Concept for a Future NASA/ESA Entry Probe Mission to the Ice Giants

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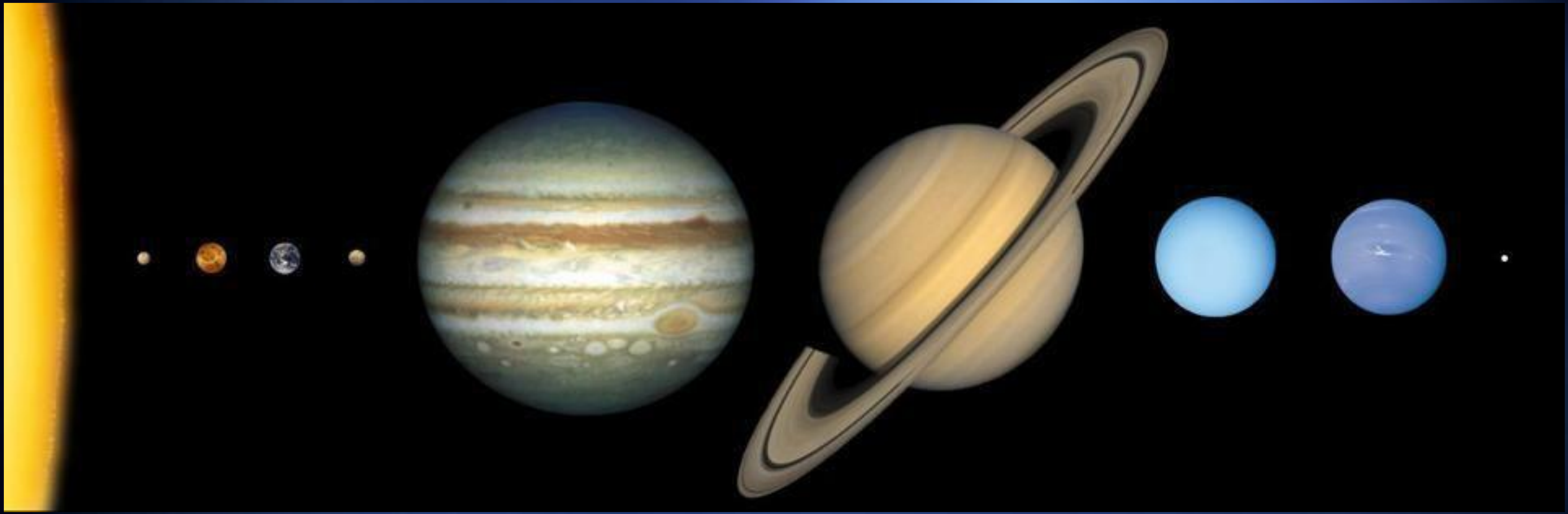
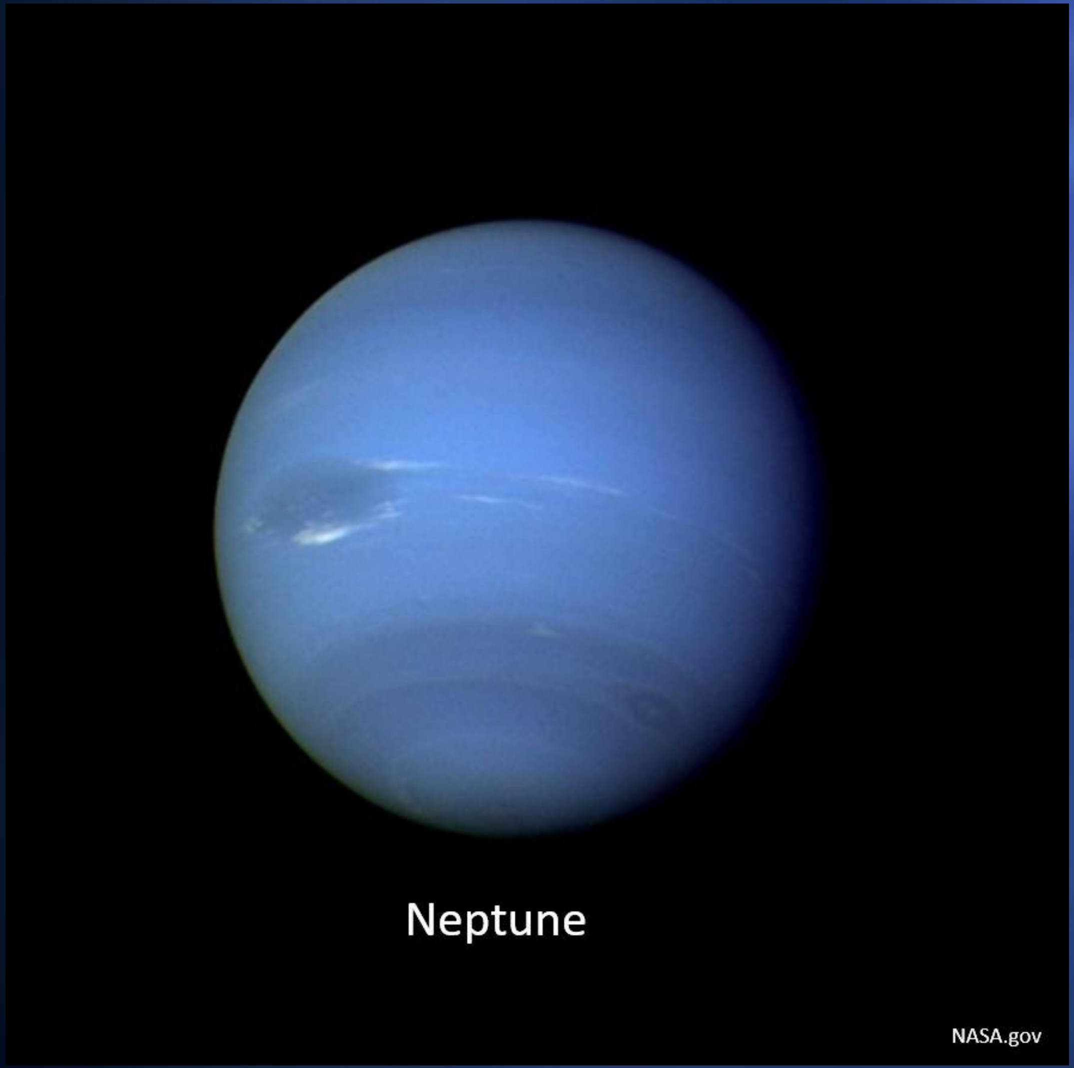
IEEE
Buenaventura MTT-S Chapter
15 May 2019

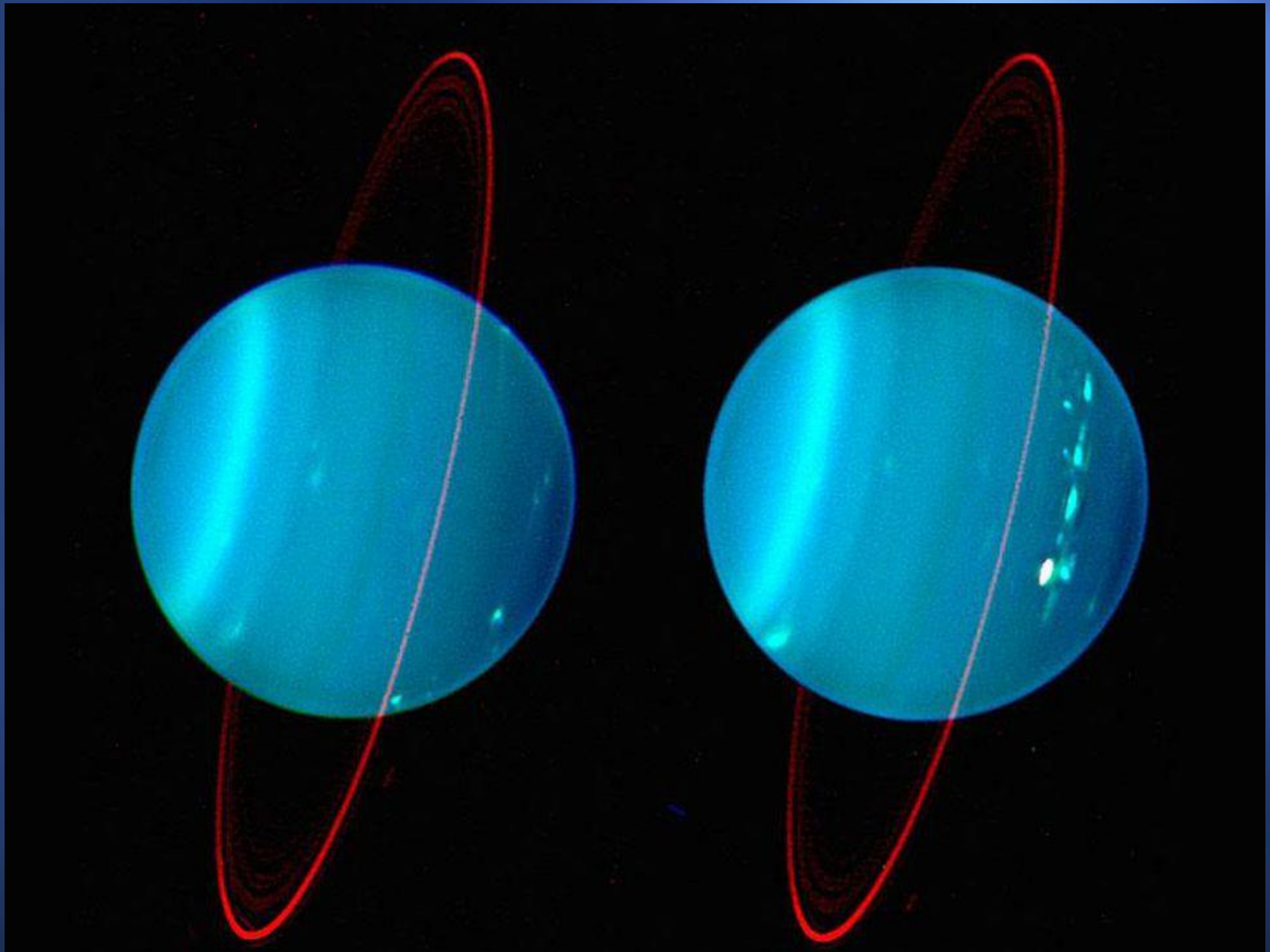
Solar System Family of Planets



Ice Giants: Neptune and Uranus

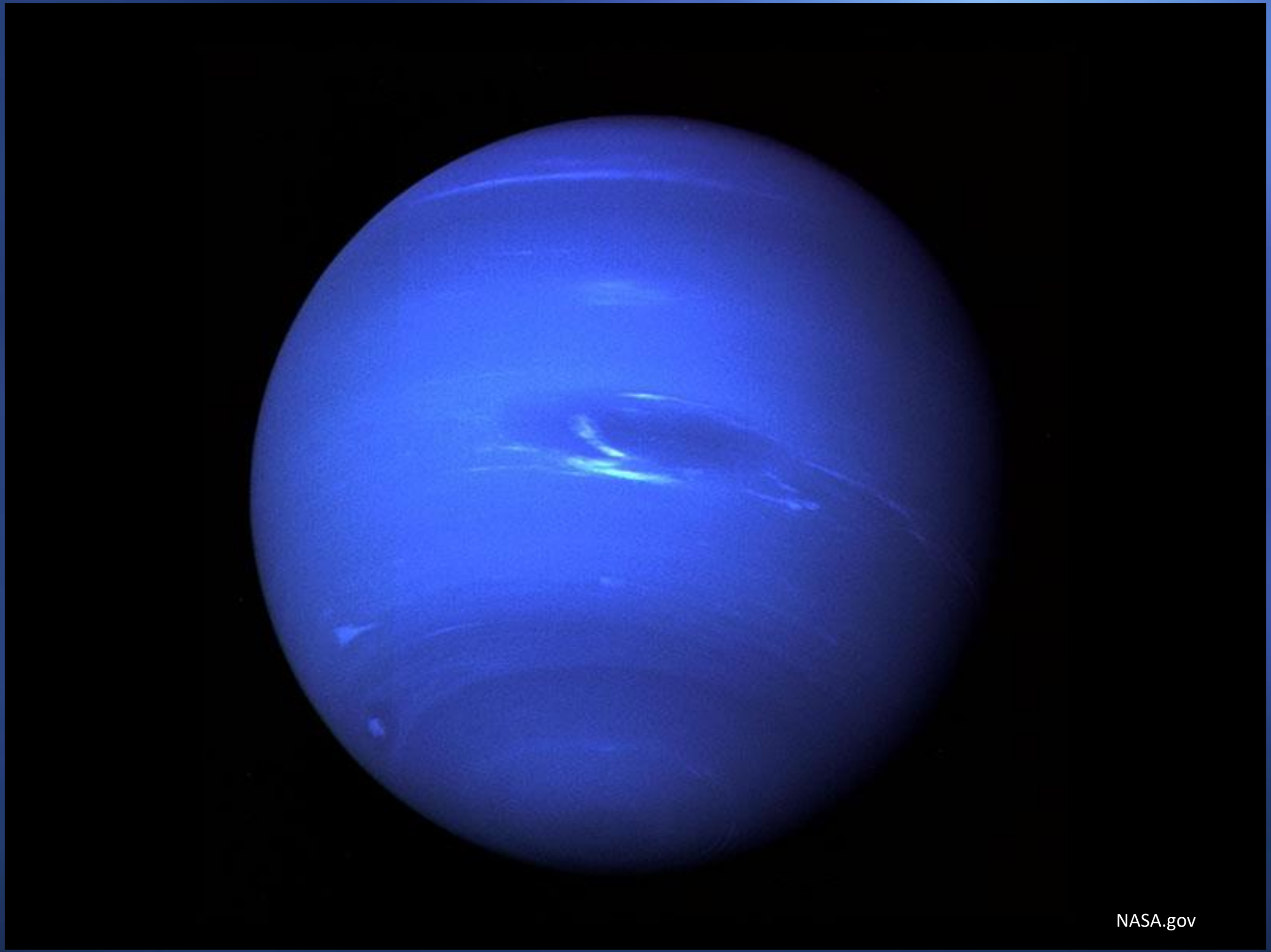


Uranus Infrared View



L. SROMOVSKY, UNIV. WISCONSIN-MADISON/W.M. KECK OBSERVATORY

Neptune

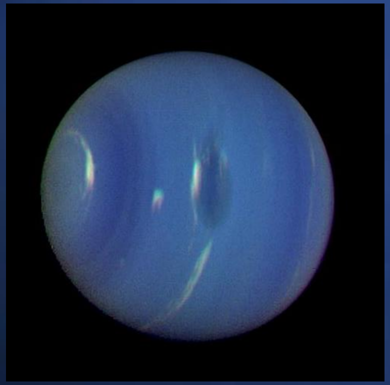


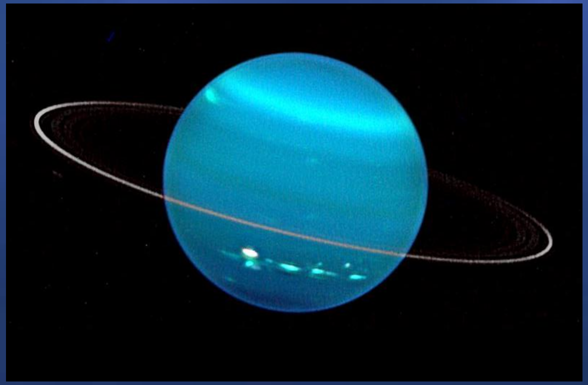
Science Justification for Outer Planet Entry Probes

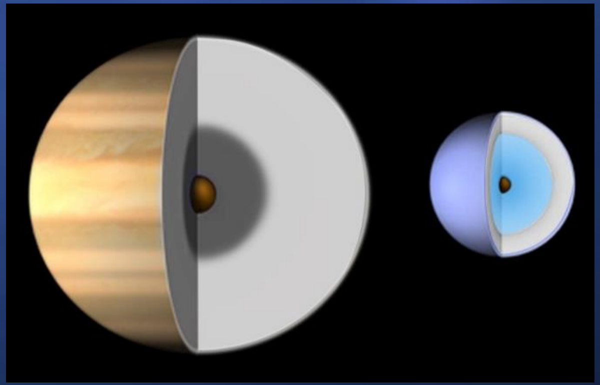
Comparative planetology *of <u>well-mixed atmospheres</u> of the outer planets is key to the origin and evolution of the Solar System, and, by extension, extrasolar systems.*

Atreya, S. K. et al., "Multiprobe exploration of the giant planets – Shallow probes," Proceedings of the 3rd International Planetary Probes Workshop, Anavyssos, Greece, 2005.

For all the capabilities of remote sensing, only *in situ* exploration by descent probe(s) can completely reveal the secrets of the deep, well-mixed atmosphere containing pristine materials from the epoch and location of giant planet formation.







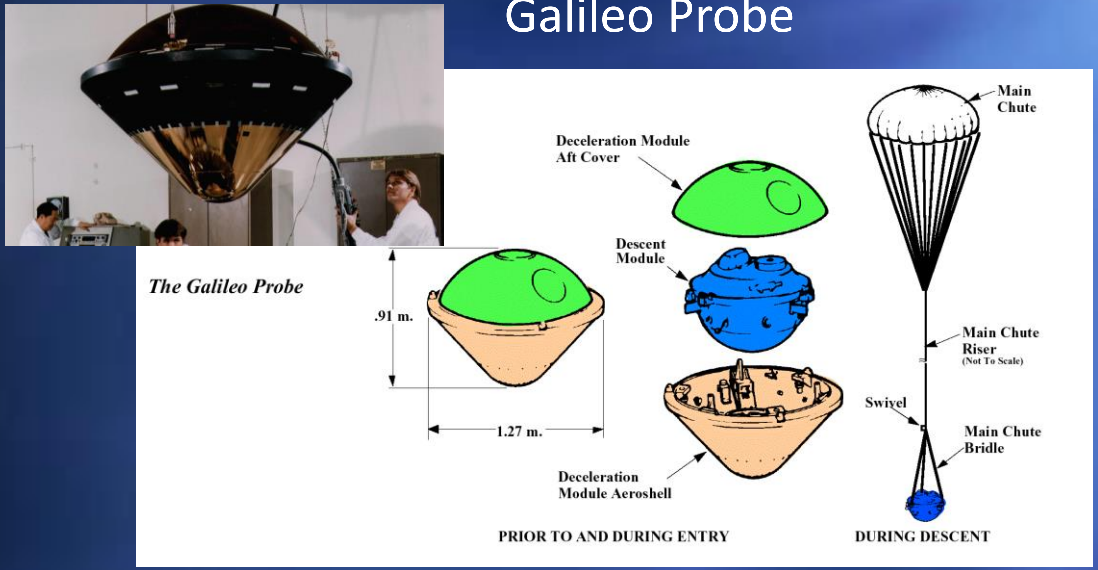
Motivation and Background

- Giant planets have played a significant role in shaping the architecture of the solar system, including the smaller, inner terrestrial planets.
- Remote Sensing has some limitations, especially to study the bulk atmospheric composition.

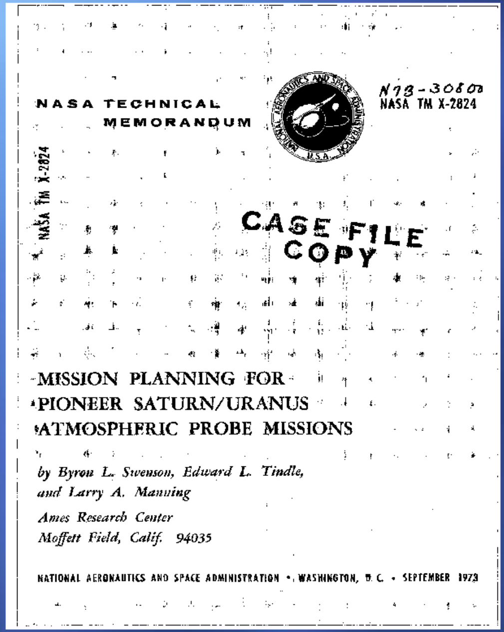
  In particular, the measurement of noble gas and helium abundances requires in situ measurements.
- The Galileo probe provided a giant step forward regarding our understanding of Jupiter.
- However, it remains unknown whether these measurements are unique to Jupiter or are representative of all gas giants including Saturn, and how the composition, processes, and dynamics of the giant planets are similar and different from the ice giants.

Heritage: Previous Studies and Previous Missions

Galileo Probe



NASA 1973


NASA TECHNICAL MEMORANDUM

N73-30803
NASA TM X-2824

NASA TM X-2824

CASE FILE COPY

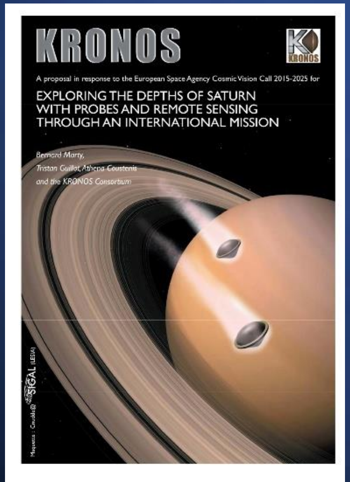
MISSION PLANNING FOR PIONEER SATURN/URANUS ATMOSPHERIC PROBE MISSIONS

by Byron L. Swenson, Edward L. Tindle, and Larry A. Manning

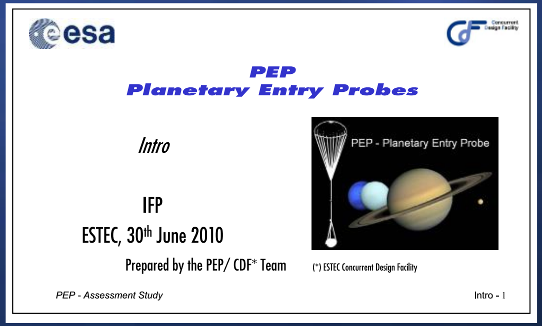
Ames Research Center
Moffett Field, Calif. 94035

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • SEPTEMBER 1973

ESA KRONOS Proposal



ESA Huygens Probe



ESA PEP Study

NASA TECHNICAL MEMORANDUM

N73-30800
NASA TM X-2824

NASA TM X-2824

CASE FILE COPY

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Key Questions

How did the solar system form?

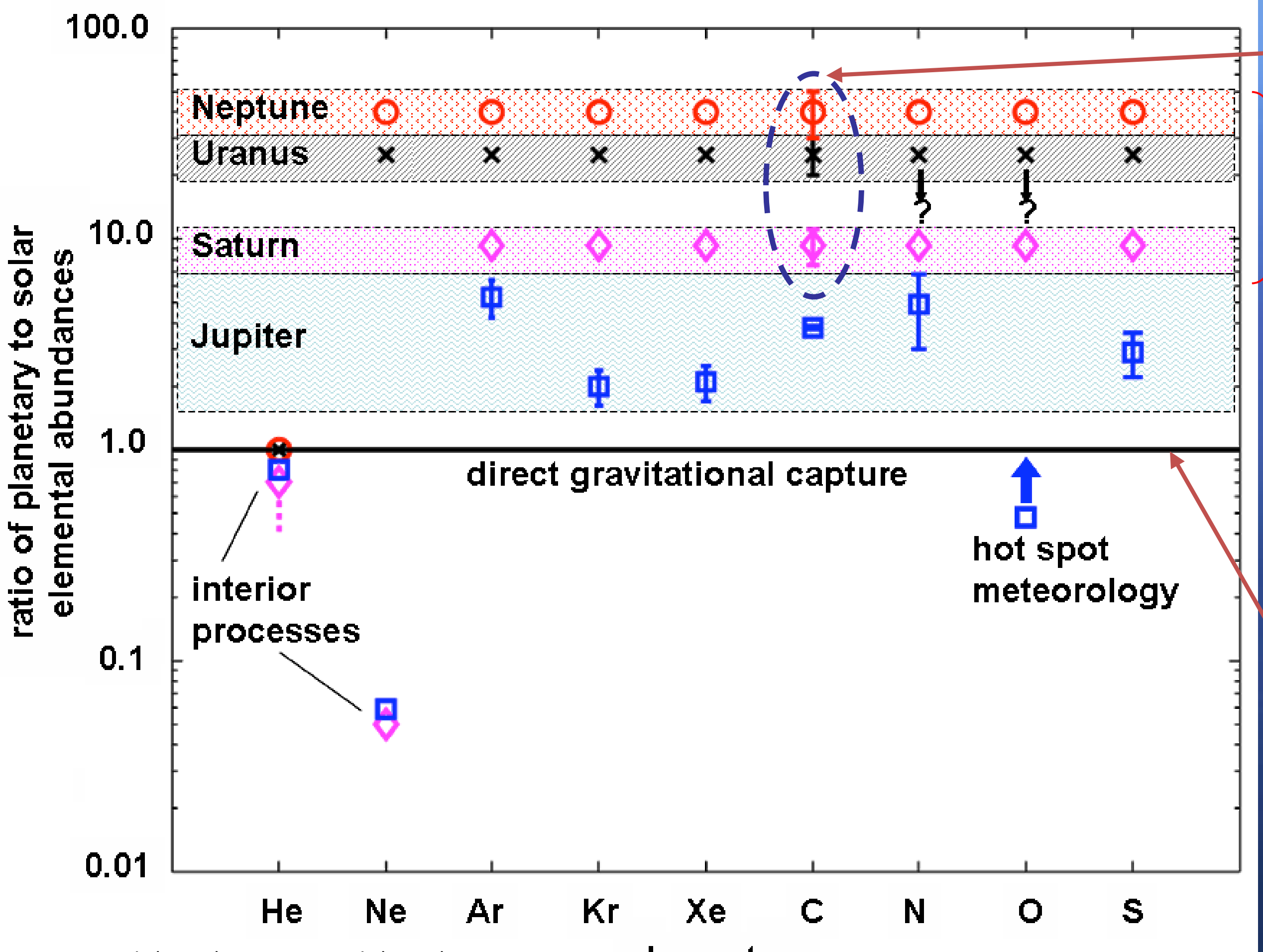
What role did the giant planets
play in promoting habitable planets?

What can be learned about
exoplanets from the giant planets?

Key Entry Probe Measurements

- **Bulk composition**: Elemental abundances including O, C, N, S, He, Ne, Ar, Kr, Xe
- **Isotopic ratios**: Noble gas isotopes, D/H, $^{13}C/^{12}C$, $^{15}N/^{14}N$
- **He/H_2 ratio**: For planetary heat balance, interior processes, and thermal history
- **Ortho/Para H_2 ratio:** For thermal structure and deep dynamics

Background
Heavy Elemental Abundances of the Giant Planets



Atreya et al. (2018), Mousis et al. (2018)

Saturn/Uranus/Neptune: only carbon is measured

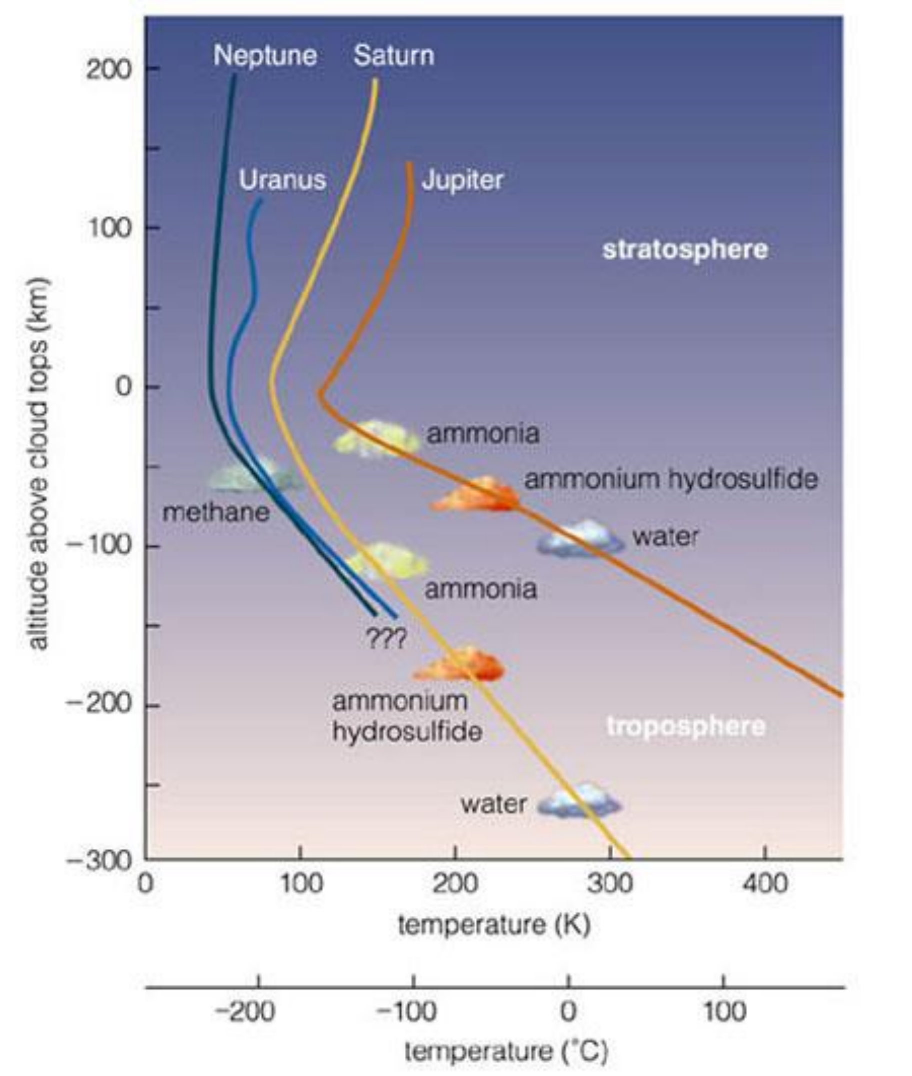
Not measured data;

Based on predictions of icy planetesimal model assuming enhancement similar to carbon

Jupiter data from Galileo Probe Neutral Mass Spectrometer

Abundances the same as in the Sun

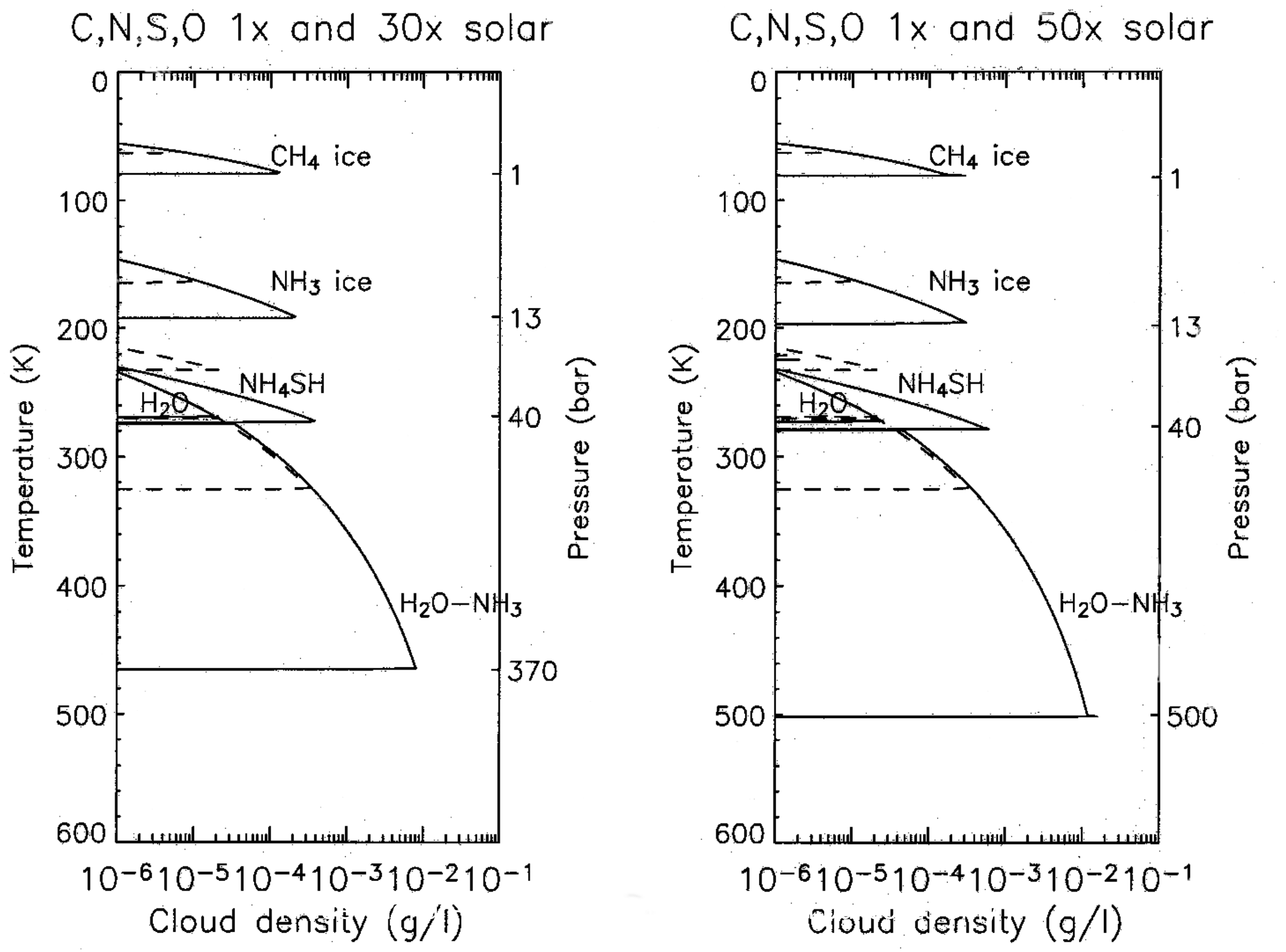
Radiation Balance and Clouds



- Remote sensing provides some constraints on cloud structure, but relies heavily on assumptions.
- A probe provides ground truth and connection to observed cloud top winds.
- *In situ* measurements can provide the thermal profile of the atmosphere.

Predicted Cloud Layers

Uranus water cloud at 500 bars: elements




NASA Vision Mission
Neptune Orbiter with Probes
Contract No. NNH04CC41C
Final Report
August 14, 2005
www.nasa.gov
Ice Giants
Pre-Decadal Survey Mission Study Report
Science Definition Team Chairs | Mark Hofstadter (JPL), Amy Simon (GSFC)
Study Manager | Kim Reh (JPL) Study Lead | John Elliott (JPL)
NASA Point of Contact | Curt Niebur
ESA Point of Contact | Luigi Colangeli
JPL D-100520
2017
National Aeronautics and Space Administration
esa
Ice Giants
CDF Study Report: CDF-187(C)
January 2019
page 1 of 431
CDF Study Report
Ice Giants
A Mission to the Ice Giants – Neptune and Uranus
Ice Giants
January 2019
ESA UNCLASSIFIED – Releasable to the Public
NASA New Frontiers Proposal, 2017
Amy Simon, PI

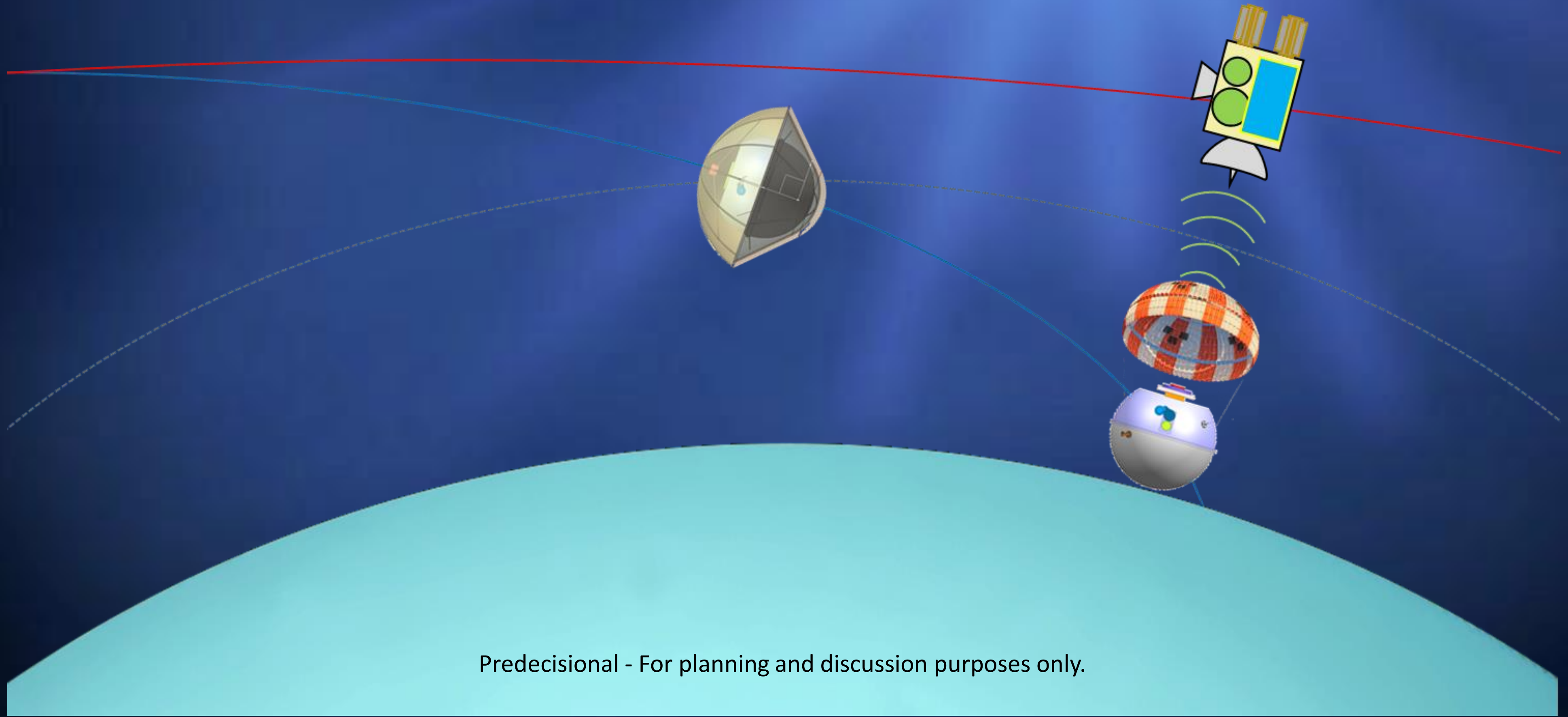
Ice Giant Probe Mission Concept

From Reh, et al. Return to the Ice Giants Pre-Decadal study summary, IPPW-14, 12-16 June, 2017

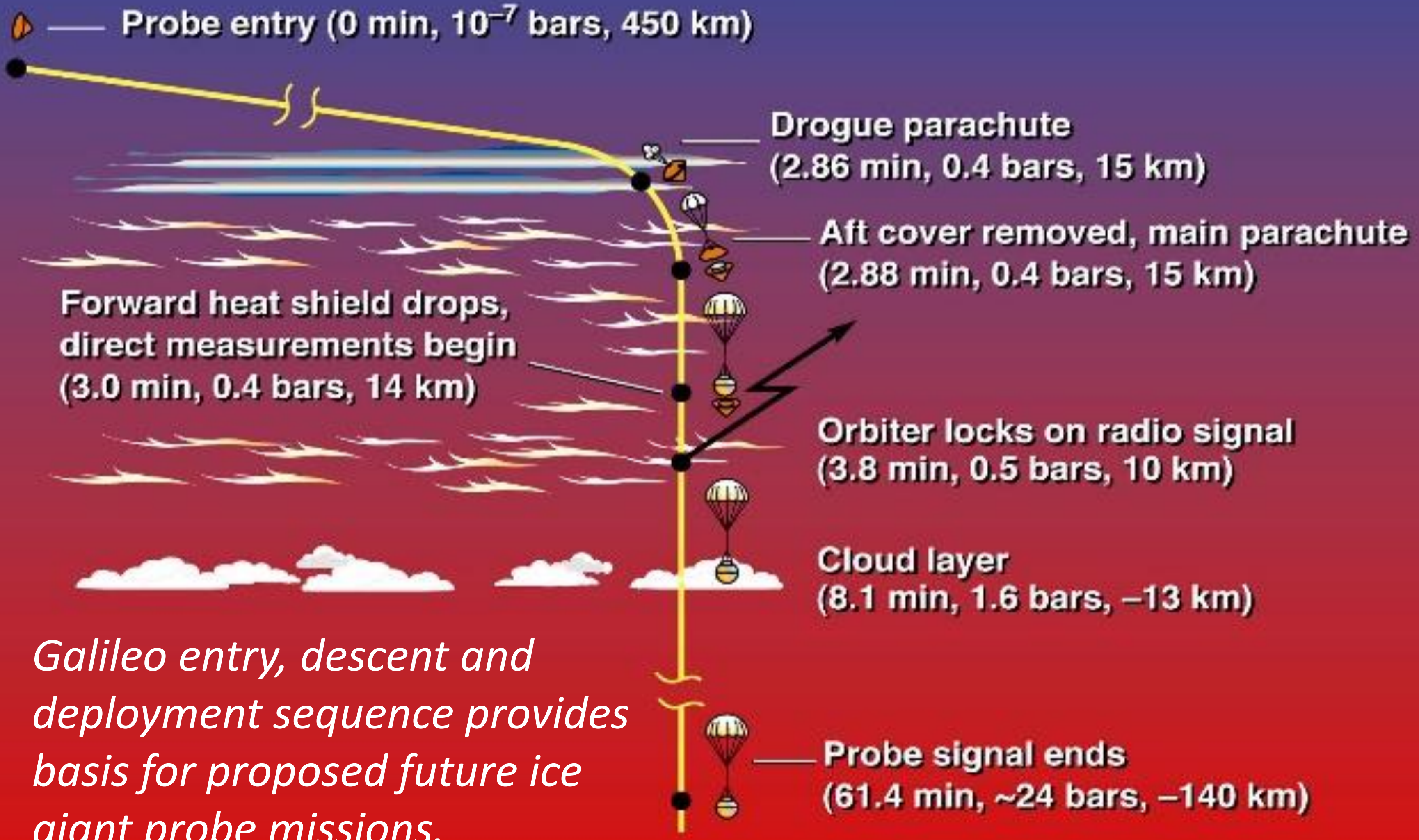
Release:
- ~60 days prior to entry
- Spin stabilized
- RHUs for coast heating

Uranus/Neptune Entry:
Entry V = 23.5/24.1 km/s

Telecomm to Carrier Relay Spacecraft:
Duration: >1 hr
Max Range: <100,000 km



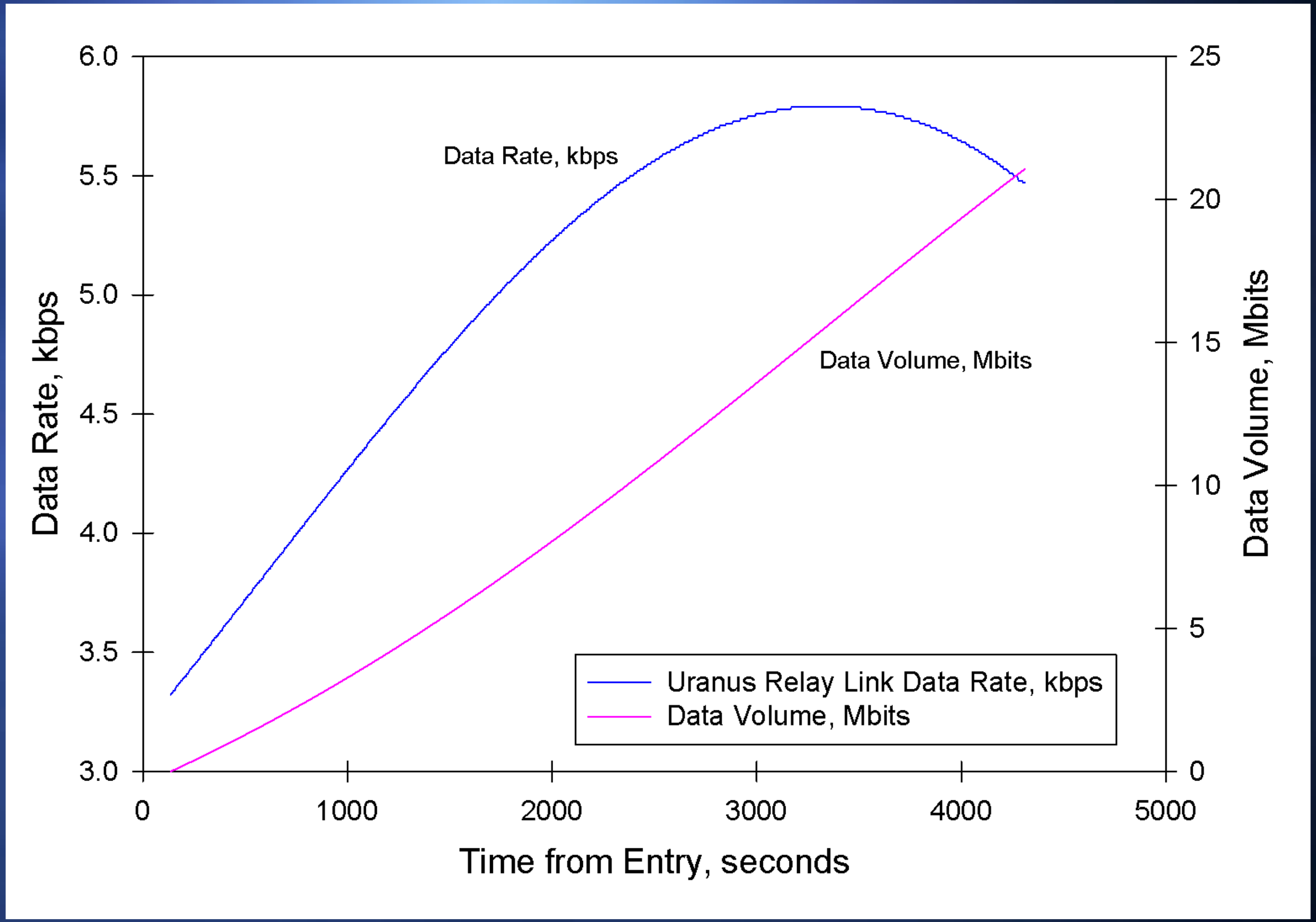
Galileo Probe Mission



Galileo entry, descent and deployment sequence provides basis for proposed future ice giant probe missions.

Telecommunications

- Ice giant atmospheres primarily H_2/He but with radio-absorbing species, primarily H_2S (hydrogen sulfide) and NH_3 (ammonia).
- At UHF frequency, atmosphere relatively clear to 12 bars (~0.15 dB) to 20 bars (~2 dB). Absorption higher at S-band from ~1 dB at 10 bars to TBD dB at 20 bars.
- Assumed telecomm link parameters (UHF)
  - Tx Power: 25 Watts
  - Tx Antenna gain: 5 dB (Galileo Probe: 9.6 dB)
  - Rx Antenna gain: 15 dB (Galileo RRA: 20.8 dB)
  - Tx Antenna 3 dB beamwidth: +/-35 deg (Galileo probe Tx: +/-28 deg)
  - Link margin: 6 dB
  - 1.5x atmospheric opacity



Entry Probe Science Objectives - Threshold

Threshold Science Objectives (5-10 bars)

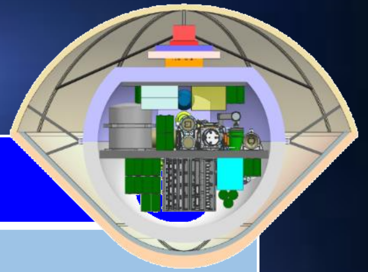
- Composition
  - Abundances of noble gases He, Ne, Ar, Kr, and Xe *(incl. isotopes)*
  - Isotopic ratios of H, C, N, and O
- Atmospheric Thermal Profile
  - Temperature vs. pressure (depth)

Entry Probe Science Objectives - Baseline

Baseline Science Objectives

- Vertical profile of zonal winds vs. depth (pressure)
- Cloud location, structure, composition, number densities
- Altitude profile of net radiative fluxes: upwelling thermal IR, deposition of solar (visible) radiation

Strawman Payload



Threshold	
Instrument	**Measurement**
Mass Spectrometer	Atmospheric composition including noble gases and key isotopes
Helium Abundance Detector	Abundance of atmospheric helium
Atmospheric Structure Instrument	Primary: Pressure and temperature → static stability, density 2ndary: descent acceleration (turbulence), atmospheric electricity/ lightning
Baseline	
Radio Science Experiment	Atmospheric dynamics: winds and waves Secondary: atmosph uwave absorption → abundance of key molecules
Nephelometer	Cloud location, structure, number densities, properties
Net Flux Radiometer	Profile of net radiative fluxes: upwelling thermal IR, deposition of solar (visible) radiation
Other	
Acoustical Properties	Speed of sound, Ratio of Ortho to Para H_2
Tunable Laser Spectrometer (TLS)	Abundance of key targeted disequilibrium species: CO, PH_3, AsH_3, SiH_4, GeH_4

Ice Giant Probe Radio Science

Highest Priority Science Objective for a Uranus Orbiter and Probe mission (PSDS 2013-2022):

"Determine the atmospheric zonal winds, composition, and structure at high spatial resolution, as well as the temporal evolution of atmospheric dynamics."

Radio Science Experiment - Background

Radiometric tracking (probe telemetry signal frequency and signal strength) of an ice giant entry probe provides

– the only direct measurement of dynamics along the probe descent path;

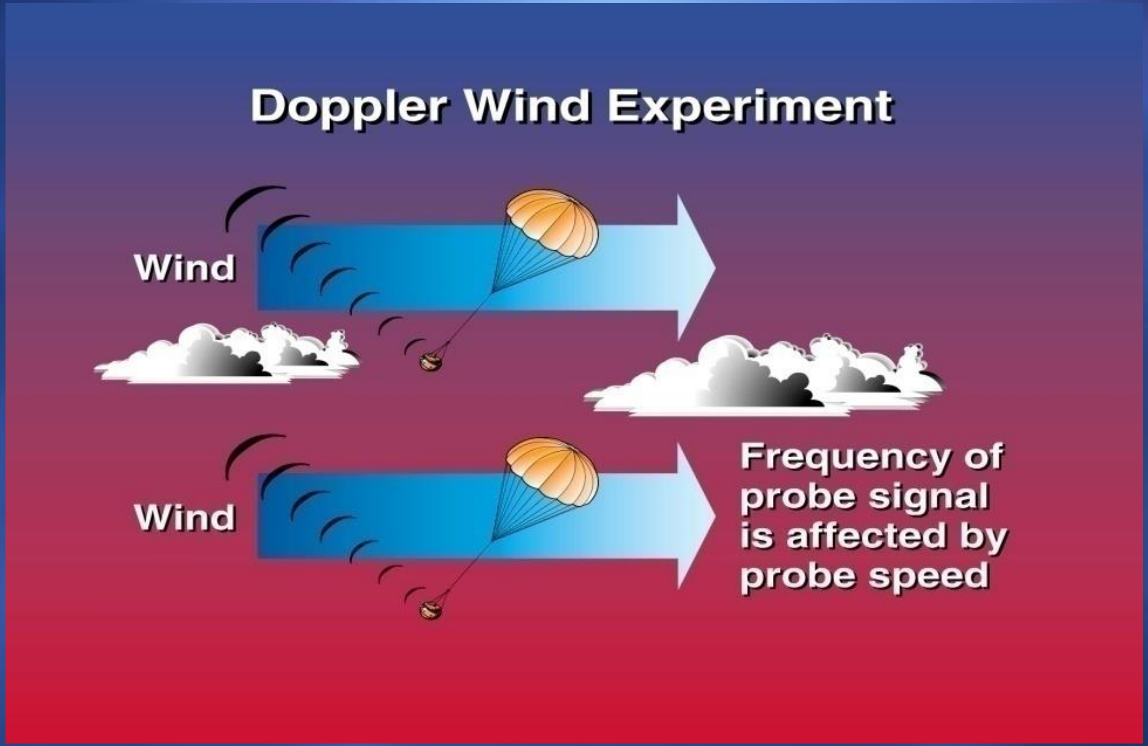
– measure of the integrated abundance of uwave absorbing molecules along probe relay signal raypath, primarily hydrogen sulfide (H_2S).

Doppler Wind Experiment

Measurements:

- Zonal winds, waves, turbulence
- Probe dynamics

  (spin, aerodynamic buffeting, pendulum motion, etc.)

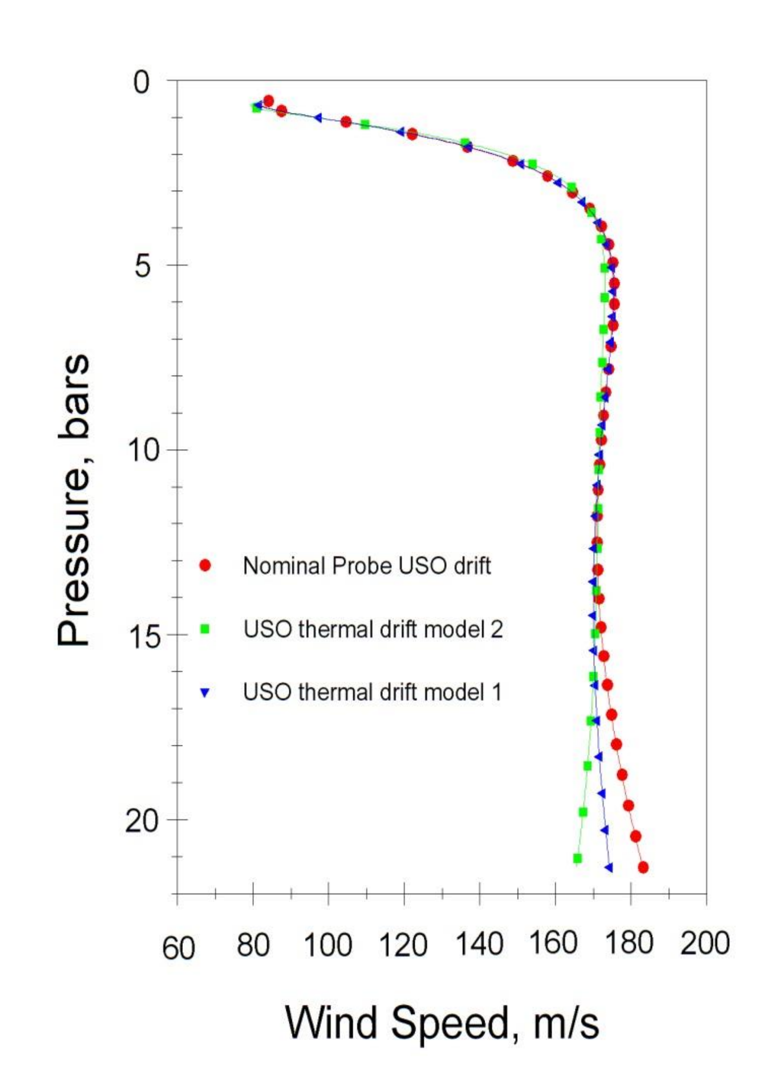


<u>Heritage:</u> Galileo (D. Atkinson, Univ. Idaho & J. Pollack, NASA Ames)

Huygens (M. Bird, Univ. Bonn)

Heritage – Galileo / Jupiter, 1995

- Probe horizontal traverse due to winds significantly larger than vertical descent under parachute.
- Probe longitude delivery error of .07 degree → equivalent Doppler frequency from 300 m/s zonal wind.
- Integrated effect of wind on probe longitude caused a Doppler contribution > 250 Hz → equivalent to ~310 m/s zonal wind.



References

Atkinson, Ingersoll, and Seiff "Deep winds on Jupiter as measured by the Galileo probe," Nature, v399 14 Aug 1997.

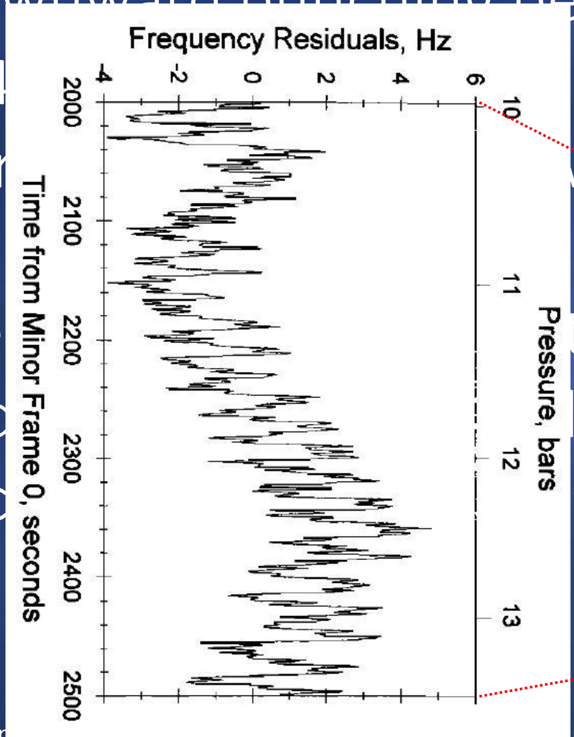
Atkinson, Pollack, and Seiff "The Galileo Doppler Wind Experiment: Measurement of the deep zonal winds on Jupiter," J. Geophys. Res., v103, E10, Sept. 25, 1998.

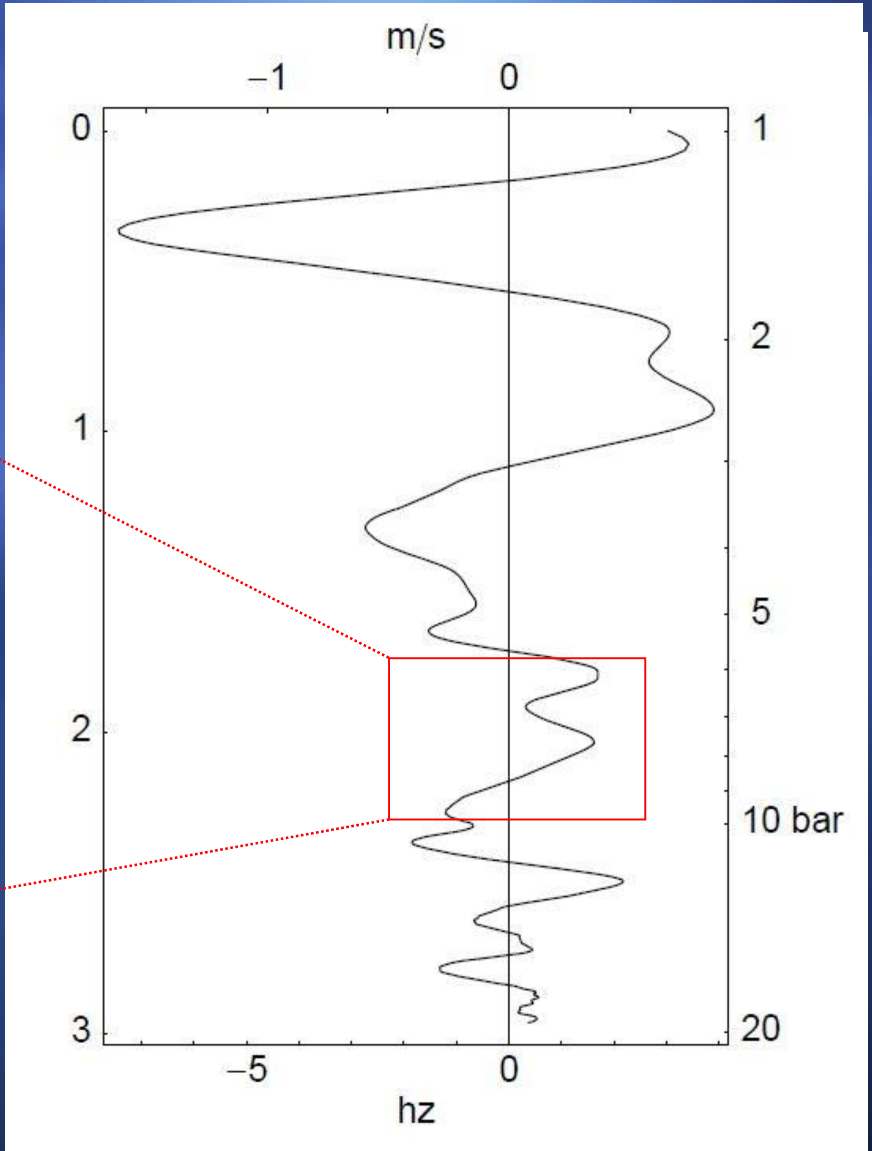
Frequency Residuals - Waves

Fine structure from probe spin, pendulum, turbulence, and aerodynamic buffeting.

Filtered residuals show downward bunching below ~ 4 ... ver ... wave.

De ... tude
Inc ...
inc ... y.





Reference
Allison and Atkinson, "Galileo Pr... ...ure of weakly stable, downward-increasing stratification in Jupiter's deep wind layer," Geophys. Res. Lett., v28, 14, 2001.

Other Considerations

Doppler Wind retrieval requires accurate reconstruction of entry interface location, entry trajectory, and descent location to ~.05 degree longitude and latitude:

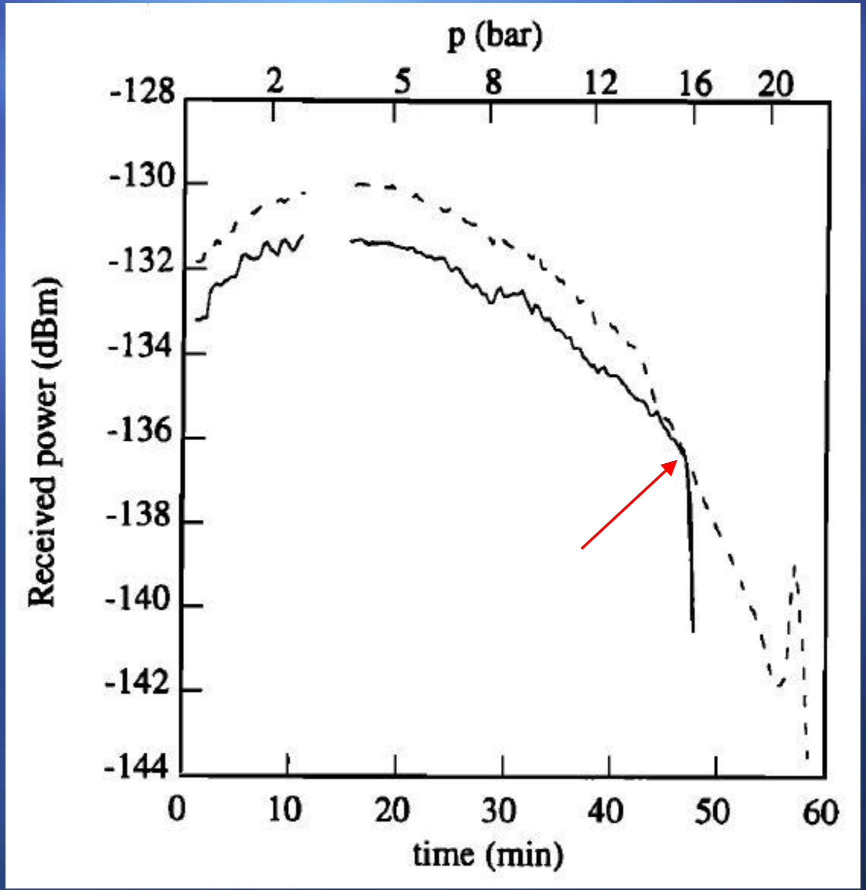
- Probe release dynamics via Doppler tracking of Carrier during release sequence
- Imaging of probe post-release for optical navigation
- Tradeoff between time of release and coast period (Galileo: 150 days / Huygens: 20 days) with power and thermal, ΔV necessary for carrier deflection, and required accuracy of entry location reconstruction.
- 3-axis entry accelerometry to reconstruct entry trajectory
- Sensors to retrieve time-varying probe mass due to heat shield ablation permits reconstruction of pressures, temperatures, and densities in upper atmosphere
- To achieve stability required for DWE, probe USO requires power-on at least several hours prior to entry.

Atmospheric Absorption

The radio signal from the Galileo probe to the orbiter experienced significant atmospheric attenuation during probe descent.

Inversion of attenuation profile provided atmospheric ammonia abundance as function of depth.

Each point represents average of 400 samples at 47 ms interval.



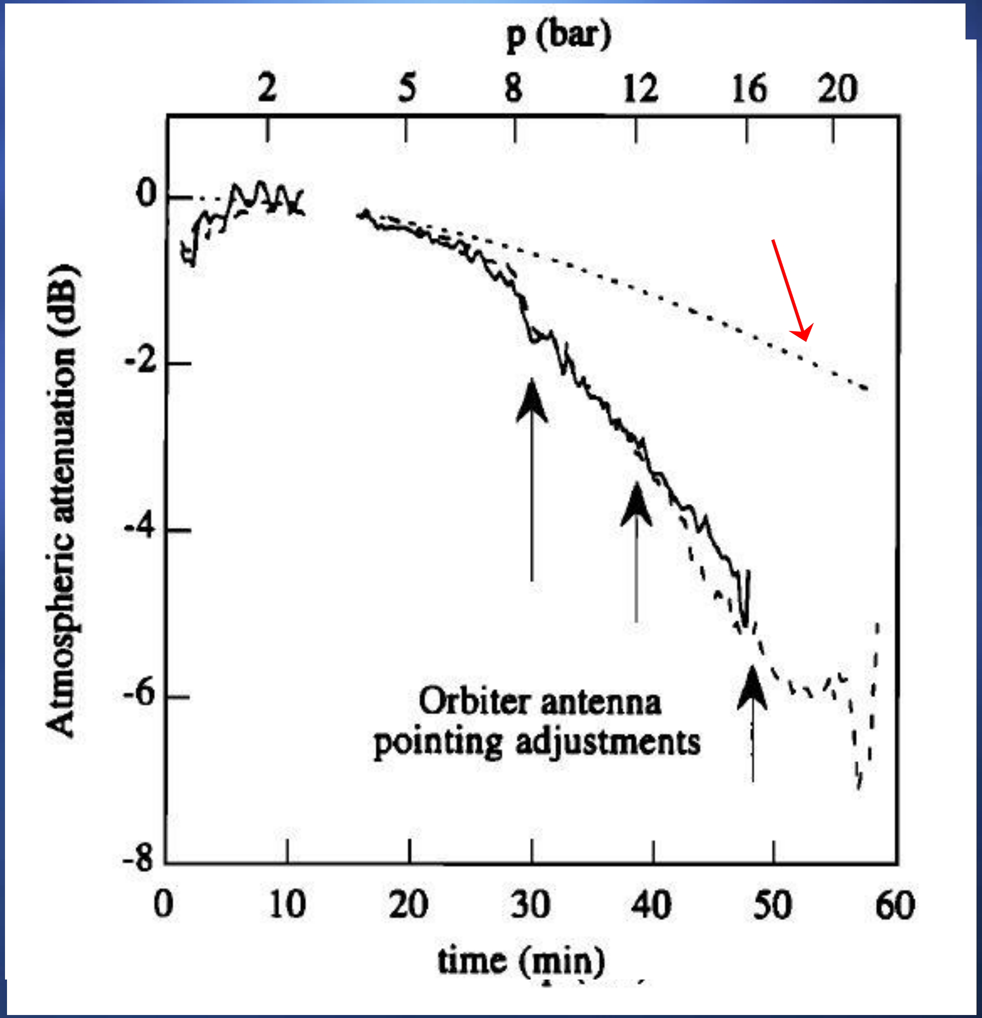
Folkner, W., et al. "Ammonia abundance in Jupiter's atmosphere derived from the attenuation of the Galileo probe's radio signal," JGR, 103, El0, Sept. 25, 1998.

Atmospheric Absorption

Amplitude of received signal sampled to study refractive index fluctuations from scintillation, turbulence, etc.

Complicated probe motions during descent introduced dynamics at similar time scales as scintillation.

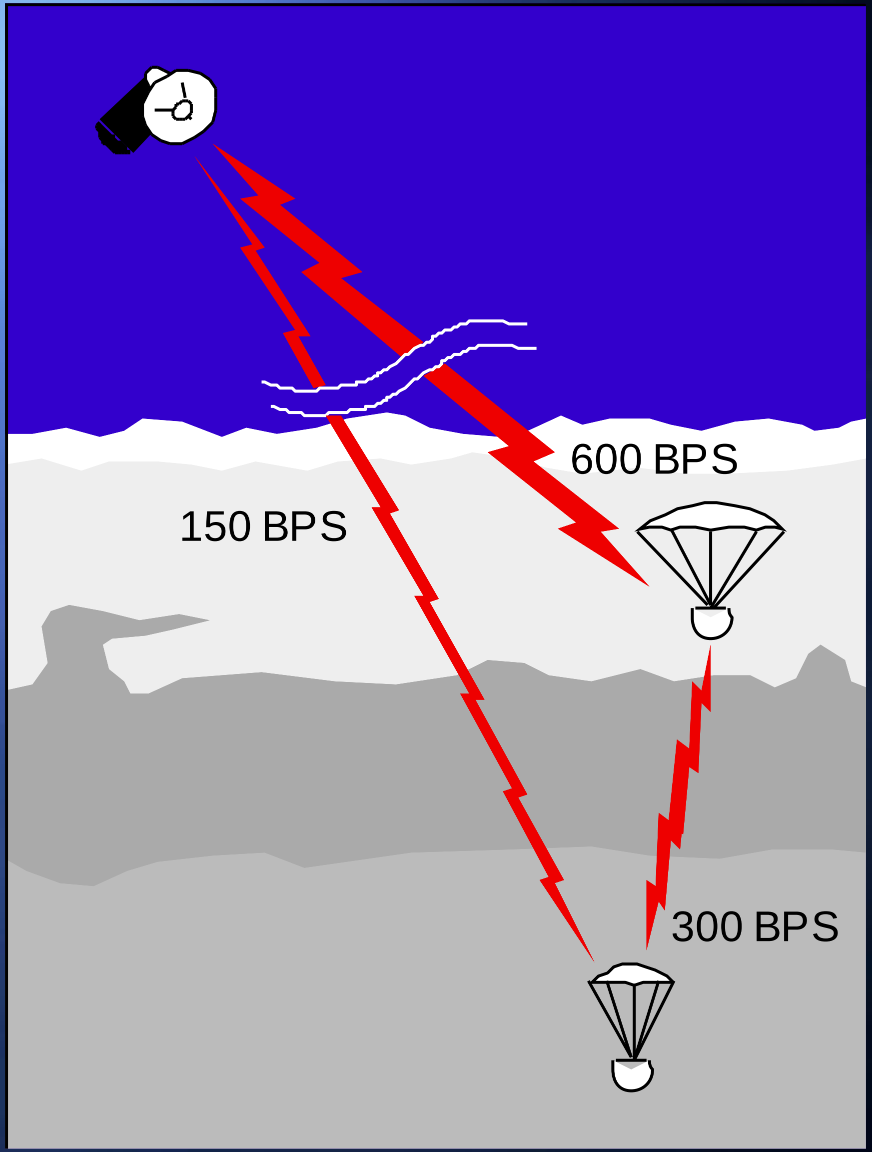
Slowly varying amplitude changes due to varying atmospheric attenuation.



Folkner, W., et al. "Ammonia abundance in Jupiter's atmosphere derived from the attenuation of the Galileo probe's radio signal," JGR, 103, El0, Sept. 25, 1998.

Deep Probe Telecommunications: Staged Probes

- Outer planet atmospheres primarily H_2/He but with significant radio-absorbing species: NH_3, H_2O.
- At UHF, shallow probes (10-20 bars) remain within relatively "clear" atmosphere → low absorption.
- Communication from deep atmosphere requires transmission through absorbing atmosphere → greatly reduced data throughput.
- Architecture Option: Shallow probe descending slowly releases deep probe for rapid descent → Offers potential to overcome RF opacity that limits deep probe telecomm data rates.



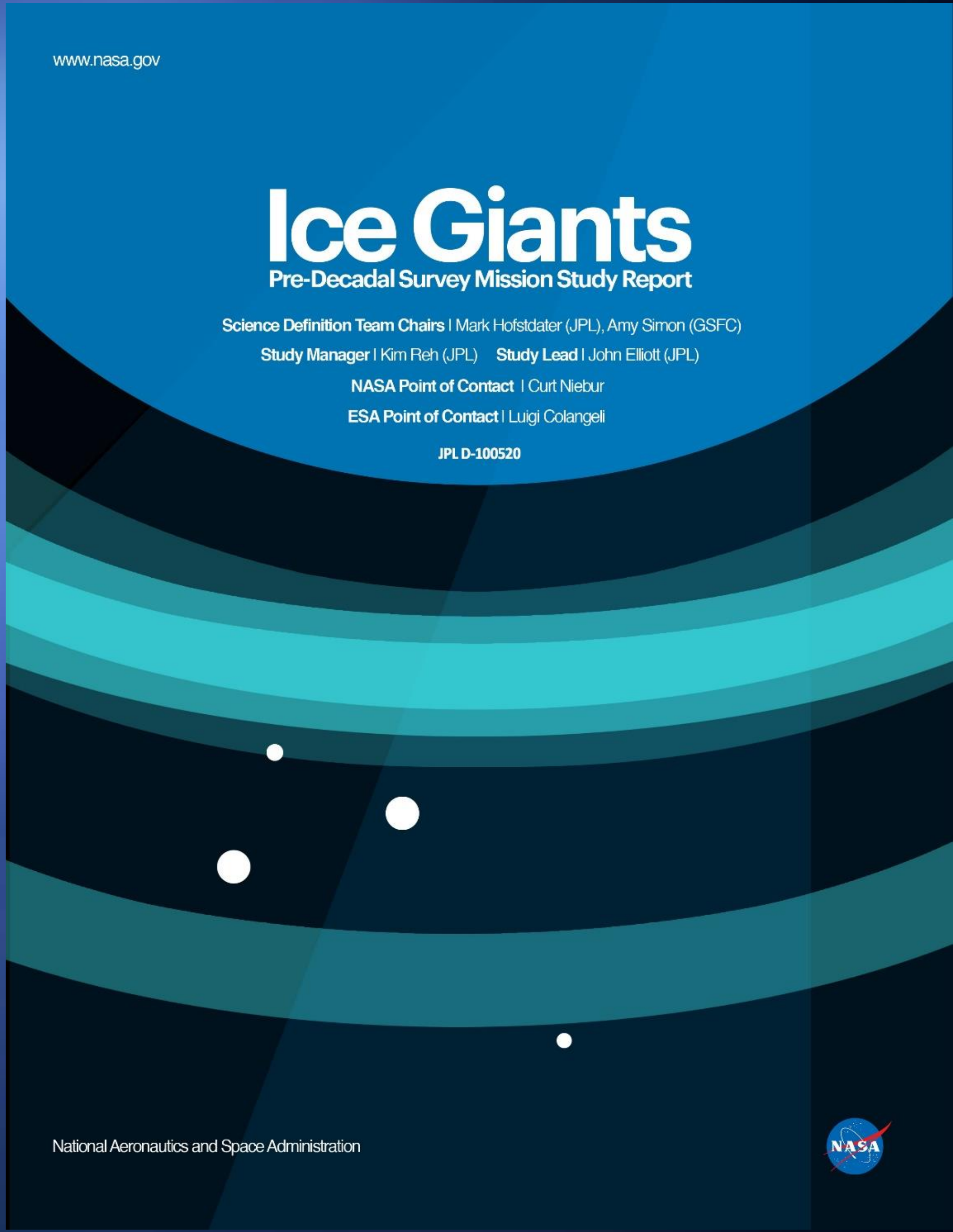
Conclusion

Achieving key goals for exploring and understanding ice giant atmospheres, and thereby constraining our knowledge and understanding of the formation and evolution of the solar system requires measurements that can only be made within the atmosphere by direct sampling of noble gases and key isotopes.

Summary

- The Giant Planets played a significant role in shaping the solar system including the formation and evolution of the terrestrial planets.
- With the exception of in situ measurements of Saturn's atmospheric composition, the Jupiter and Saturn systems have been explored in detail. The last largely unexplored class of planets is the Ice Giants.
- Remote Sensing is a very powerful technique, but is unable to measure essential components of the atmosphere, noble gases and key isotopes in particular.
- The legacy of the Galileo probe mission directly translates to concepts for future planet entry probe missions to Saturn and the ice giants.

Future ice giant explorations require an in situ element that will draw heavily on the experience of the Galileo probe, and outer planet probe mission concept studies.



Thank You!

Questions?

References

Atreya, S. and T. Owen, "Multiple Probes to Multiple Planets," 3rd International Planetary Probe Workshop, Athens, 2005.

Hofstadter, M. and K. Reh, "Ice Giants, Pre-Decadal Study Summary," ESA Headquarters Presentation. 31 January 2017

Mousis, et al., "Scientific rationale for Uranus and Neptune in situ explorations," Pl. Sp. Sci., 155, 12-40, 2018. https://doi.org/10.1016/j.pss.2017.10.005

Reh, K., et al., "Return to the Ice Giants Pre-Decadal study summary," International Planetary Probe Workshop, 12-16 June, 2017

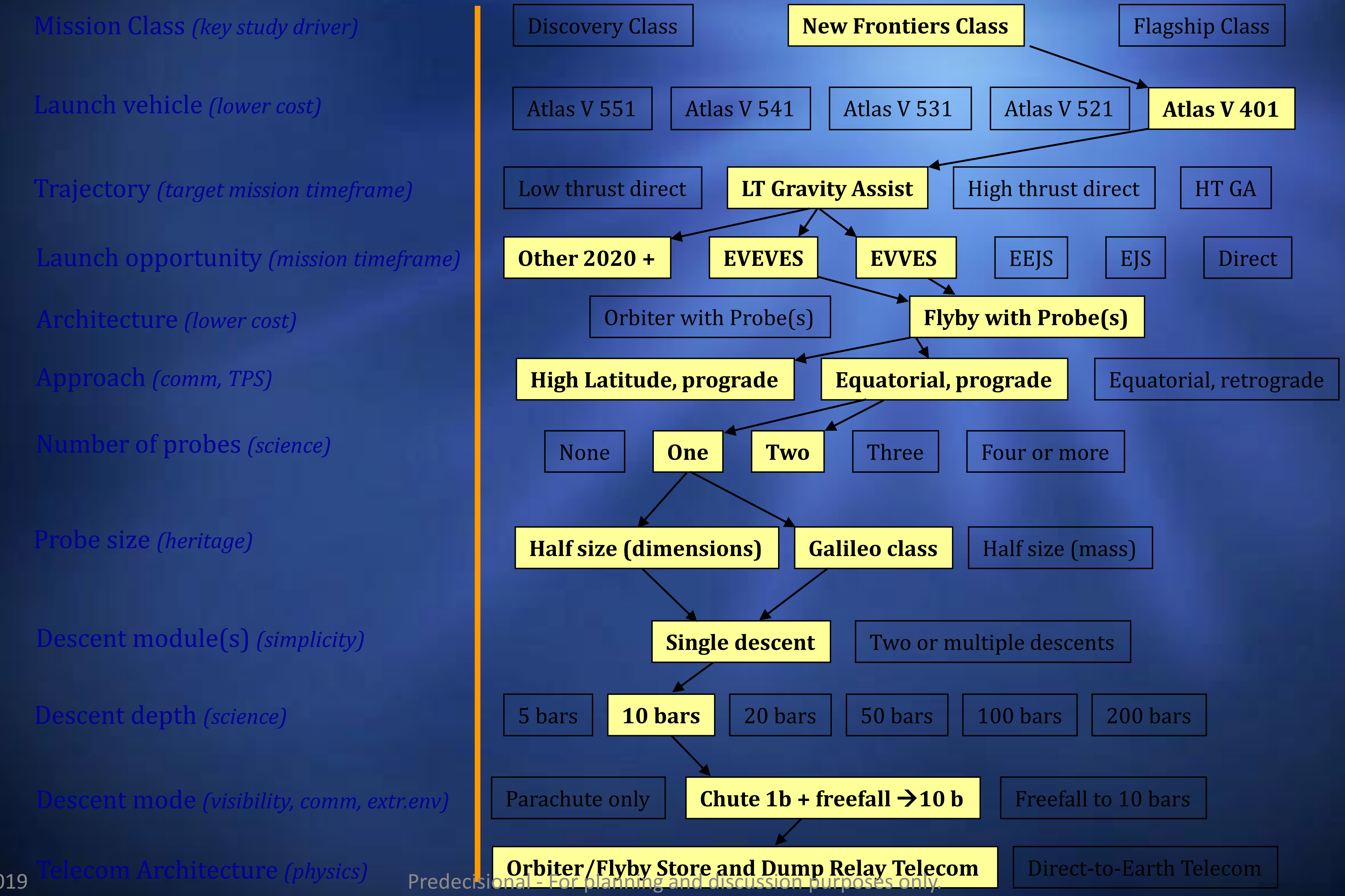
Sayanagi, K.M., et al., "Small Next-generation Atmospheric Probe (SNAP) Concept," 14th Int. Planetary Probe Workshop, The Netherlands, June, 2017.

Spilker, T.R, "Planetary Entry Probes In the Foreseeable Future: Destinations, Opportunities, and Techniques," 1st International Planetary Probe Workshop, Lisbon, 2003.

Spilker, T.R. and D.H. Atkinson "Saturn Entry Probe Potential for Uranus and Neptune Missions," 9th International Planetary Probes Workshop, Toulouse, France, 2012.

Squyres, S., et al., 2013-2022 Planetary Science Decadal Survey Vision and Voyages. National Academies Press, Mar. 7, 2011; https://solarsystem.nasa.gov/docs/131171.pdf

Previous Trade Elements & Decision Drivers



(adapted from Balint et al., 2006)

Instrument Suite - Galileo Probe

Instrument	Mass	Power	Bit rate	Volume	Special Acc. Requirements
Atmosphere structure instrument (ASI)	4.0 kg	6.3 W	18 bps	3100 cm^3	Pressure inlet port; temperature sensor outside boundary layer; 12,408 bits storage
Nephelometer (NEP)	4.8 kg	13.5 W	10 bps	3000 cm^3	Free-stream flow through sample volume; 800 bits data storage; pyro for sensor deployment
Helium abundance detector (HAD)	1.4 kg	1.1 W	4 bps	2400 cm^3	Sample inlet port
Net flux radiometer	3.0 kg	10.0 W	16 bps	3500 cm^3	Unobstructed view 60° cone +/-45° with respect to horizontal
Neutral mass spectrometer (NMS)	12.3 kg	29.3 W	32 bps	9400 cm^3	Sample inlet port at stagnation point
Lighting and radio emission detector/ energetic particle detector (LRD/EPI)	2.5 kg	2.3 W	8 bps	3000 cm^3	Unobstructed 4P Sr FOV; RF transparent section of aft cover, 78° full cone view at 41° to spin axis
Total	**28 kg**	**62.5 W**	**128 bps$^+$**	**24,400 cm^3**	

An example of a “focused” Instrument suite that addresses a subset of critical science measurements would only include those underlined in red.

Science Justification for Exploring Giant Planets

Comparative planetology *of well-mixed atmospheres of the outer planets is key to the* ***origin and evolution of the Solar System****, and, by extension, Extrasolar Systems.*

Atreya, S. K. et al., "Multiprobe exploration of the giant planets – Shallow probes", Proceedings of the 3rd International Planetary Probes Workshop, Anavyssos, Greece, 2005.

There is only one Rosetta Stone in the solar system and it's in the British Museum. We cannot hope to understand the big problems of ***origin and evolution*** *by studying only one planet or one comet. Indeed, we must be able to make* ***comparative*** *studies even to understand a single planet. Thus our strong need to improve our knowledge of Jupiter is inextricably coupled to the necessity to achieve a comparable understanding of Saturn, Uranus and Neptune.*

Owen, T., "Atmospheric Entry Probes: Needs and Prospects", Proceedings of the 1st International Planetary Probes Workshop, Lisbon, 2003.

Probe Science Payload

Instrument	Measurement
Mass Spectrometer (MS)	Elemental and chemical composition including noble gases and key isotopes
Atmospheric Structure Instrument (ASI)	Pressure and Temperature, Entry and Descent Accelerations → Density
Radio Science Experiment	Atmospheric dynamics: winds and waves; atmospheric absorption → composition
Nephelometer	Cloud structure, aerosol number densities and characteristics
Net Flux Radiometer	Net radiative fluxes: upwelling thermal IR, solar energy
Helium Abundance Detector	Helium Abundance

Strawman Science Payload

Probe Science Instrument Payloads

Instrument	Measurement
Mass Spectrometer	Elemental and chemical composition, especially noble gases and key isotopes
Atmospheric Structure Inst.	Pressure and Temperature → Thermal structure, density, stability Entry Accelerations → Density
Radio Science Experiment	Atmospheric dynamics: winds and waves; Atmospheric absorption → composition
Nephelometer	Cloud structure, microphysics, aerosol number densities & characteristics
Net Flux Radiometer	Net radiative fluxes: Thermal IR, solar visible
Helium Abundance Detector	Helium Abundance